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TAPERING OF POLYMER OPTICAL FIBERS FOR COMPOUND PARABOLIC CONCENTRATOR FIBER TIP FABRICATION

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Abstract: We propose a process for Polymer Optical Fiber (POF) Compound Parabolic Compound (CPC) tip manufacturing using a heat and pull fiber tapering technique. The POF, locally heated above its glass transition temperature, is parabolically tapered down in diameter, after which it is cut to the desired output diameter and finally polished to obtain the special CPC tip. The physical mechanism responsible for giving a CPC shape to the POF tip is also investigated. The fabrication process is shown to be sensitive to several manufacturing parameters, such as temperature of the heat source, thermal flux from the heat source, and heating time. We further consider the influence of the heating time latter parameter on the geometry of the obtained CPC fiber tips.

Key words: Compound parabolic concentrator, polymer optical fiber, fluorescence-based sensors, viscoelastic materials, polymers.

1. Introduction

A Compound Parabolic Concentrator (CPC) is a non-imaging optical component widely used to concentrate sunlight in solar energy systems. Figure 1(a) illustrates the geometry of an ideal CPC shape. Recently CPCs have drawn attention in polymer optical fiber (POF) devices as they are able to increase the numerical aperture of the fiber. In particular, a CPC fiber tip can be employed in fluorescence-based sensors to improve the excitation and fluorescence pickup efficiency compared to the plane-cut fiber tip. In this paper we proposed a heat and pull method for CPC tip fabrication in POFs. We also investigate the influence of heating time on the geometry of the obtained CPC fiber tips.

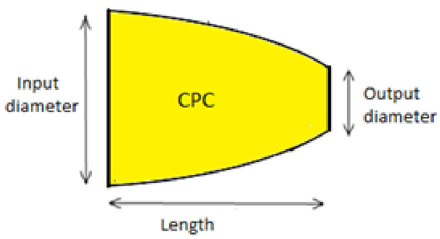

Fig. 1. Ideal CPC fiber tip.

2. CPC tip manufacturing method

2.1. Experimental

A CPC shaped POF tip can be manufactured by parabolic tapering the fiber, cutting it to the desired diameter using sclapel, and then polishing it. To reduce this extra step of polishing the fiber in CPC tip formation, electronically controlled polymer optical fiber cleaver can also be used[1]. Tapering is done by heating the fiber above its glass transition temperature (Tg) and then pulling it with a constant speed.

The commercial super ESKA™, 0.25 mm POF has been used to manufacture CPC tips. The fibers were first annealed, as recommended by Akrema Inc. [2], in an oven where the temperature is ramped up from 25 to 90°C at 10°C/hour and kept at this temperature for 5 min before ramping down to 25°C at 15°C/hour. This is to reduce the residual stresses in the fiber, which were built during the fiber drawing process.

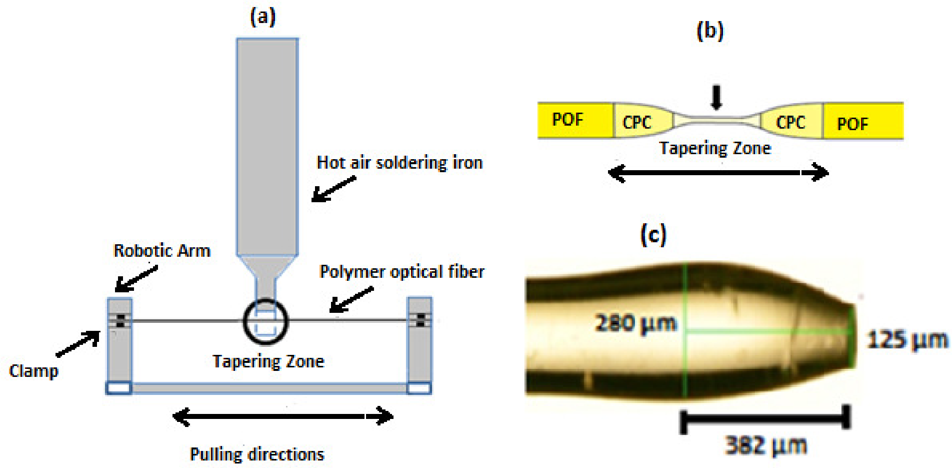

Fig. 2. a) Scheme of the polymer optical fiber tapering process. The fiber is fixed between clamps and pulled with robotic arms for tapering (b) The tapering zone in details. c) Microscope image of the increase in diameter that typically occurs at the beginning of the tapered zone.

As shown in Figure 2(a) and Figure 2(b), the fiber is mounted on the clamps between two robotic arms. A hot air soldering iron with a nozzle diameter of 2mm heated the short zone of the fiber up to 190^{o}C for 5-10 seconds. After a pre-set heating time the fiber is pulled by the robotic arms with a pre-set constant speed and pulling distance. Manufacturing parameters, such as temperature, pulling speed, pulling distance, and air pressure, were optimized to get the desired tapering length with specific tapering ratios suitable to make CPC tips.

An example of a tapered fiber is shown in Figure 3. It is cut at the two indicated places shown in the figure and polished to the required output diameter of 125 µm . Each pull thus resulted in two CPC tips.

Figure 3: Tapered fibers cut at indicated position and polished to get CPC tips.

The CPC tips made from the above method were not completely uniform in shape. An undesired feature is that, at the start of a CPC, the diameter increases and is larger than the original fiber diameter of 250 µm, as shown in Figure 2(c). Two batches each containing ten CPCs were made using this method. The time gap between the manufacturing of each batch was 3 days, i.e., the second batch was made 3 days after the first batch. The time between each tapering process to make CPCs among a single batch was approximately 10 minutes. Overall the manufacturing parameters for the two batches were the same, except for the heating time, which was 10 and 5 seconds for the 1st and 2nd batch, respectively.

2.2. Results and discussion

Figure 4(a) shows the CPC shape obtained using the proposed method, which resembles the ideal CPC shown in Figure 1. Figure 4(b) describes the average increase in the diameter for both batches with respect to the original fiber diameter i.e. 250 µm. It shows that an increase in heating time leads to increasing the maximum diameter.

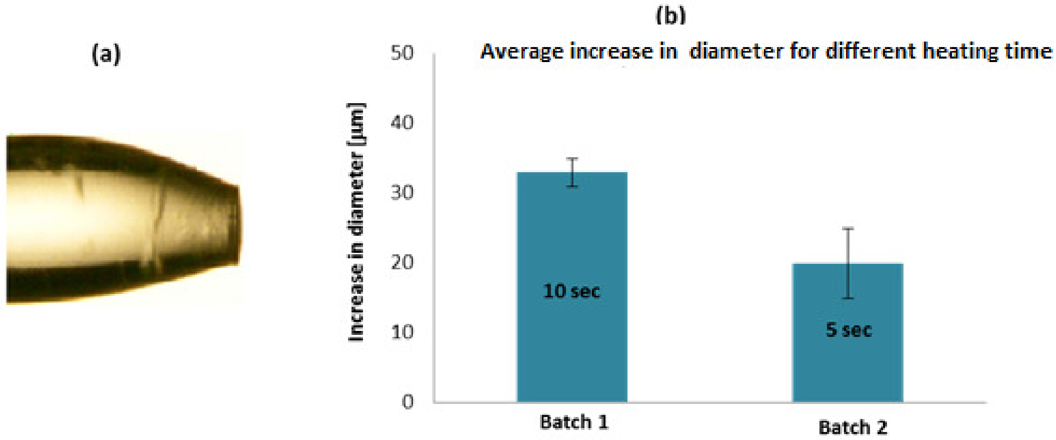

Fig. 4. a) CPC shape obtained using the proposed method. b) Average increase in diameter of two batches(with respect to the reference diameter of 250 µm) for different heating time.

This increase in the diameter is probably due to transportation and redistribution of the melted polymer, caused by the combined effect of the hot air flow and surface tension. The latter may play an important role in the breakup of polymer melts (that is polymers in the molten state [3]), since the heat flow also changes the initial surface curvatures. Note that a polymer melt can theoretically be treated as a viscoelastic fluid [4]. Many authors investigated the break-up of viscoelastic fluids, also considering the specific role of surface tension [5-8]. The proposed CPC POF tip manufacturing process is rather fast. Furthermore, the diameter of the POF becomes thinner and thinner within the tapering zone. Therefore both viscoelasticity and capillary action might influence the stability of the viscoelastic filament under processing. Another possible cause of the increase in diameter is the viscoelastic relaxation of the polymer chains surrounding the polymer melt. The effect of both on the increase of the diameter depends on the heating time. In the fiber drawing process [9] the polymer chains, randomly oriented in the preform (assuming it is isotropic), are aligned along the draw direction, so that the resulting diameter is smaller than that in a random configuration. However, for entropic reasons, they tend to return to a random state. This leads to an increase in diameter once they are heated up to the temperature sufficiently above Tg [10]. Overall, the unnecessary increase in the diameter can be reduced by decreasing the heating time, as shown in Figure 4(b).

The whole process of parabolic tapering in order to obtain a perfect CPC fiber tip is sensitive to any change in experimental configuration. Indeed, for a specific choice of materials and geometry, the final tip shape will depend on the combined effect of several process parameters, such as temperature and pressure of the heating source, heat power, exposure time, distance between heating nozzle and fiber, and pulling speed. Furthermore, both initial fiber alignment with respect to the heating nozzle and initial tension applied to the fiber, which in turns depends on the way it has been fixed, may also affect the final result. Not to mention the influence of temperature and humidity, if the process takes place in an open environment. Some authors report that even the annealing time and temperature may have a relevant influence on the mechanical behavior of polymer optical fibers [10]. A complete tapering analysis depending on these parameters is out of the scope of this paper.

3. Conclusions

We showed that CPC tips can be manufactured by the proposed method. The process is complex and sensitive to several parameters, in particular heating time. However, further understanding is required to optimize the process so as to produce perfect CPC shapes.

Acknowledgements

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